

Docket No.: SL-103

Harrington & Smith, LLP Docket No.: 907A.0112.U1(US)

Patent Application Papers of: Eric K. Hall, Richard B. Ertel, Daniel Griffin,  
Thomas Giallorenzi

**METHOD AND SYSTEM FOR BASEBAND AMPLITUDE LIMITING**

**Method and System for Baseband Amplitude Limiting****CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is related to copending U.S. Application No. \_\_\_\_\_ (Attorney Docket No. 907.0111.U1(US)), filed \_\_\_\_\_. The disclosure of this Non-provisional Patent Application is incorporated by reference herein in its entirety.

**BACKGROUND OF THE INVENTION****1. Field of the Invention**

The present invention relates to digital communication systems and, more particularly, to baseband amplitude limiting in code division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM) communication systems.

**2. Prior Art**

Many digital communications systems utilize amplitude and phase modulation, producing complex baseband signals, which are pulse shaped before modulation to the carrier frequency. The complex, baseband signals are typically represented as an in-phase signal (I) and a quadrature signal (Q). For many modulation formats and multiple access schemes, these complex baseband signals have large peak values relative to the average signal value. When the peak-to-average power ratio of the baseband signal is large, the signal requires reduction in the power amplifier to avoid saturation. The peak-to-average power

ratio limits the average power that can be transmitted due to the finite maximum output power of the power amplifier in the RF front-end (RFFE). Alternatively, for a fixed average transmit power, the peak to average power ratio will determine the required maximum output power of the RF power amplifier. In both cases, a decreased peak-to-average power ratio is desirable.

To decrease the peak-to-average power ratio of the signal, many digital communications systems employ clipping, also termed amplitude limiting, on the baseband complex signal. Clipping suppresses the signal peaks, reducing the peak-to-average power ratio of the signal with minimal distortion to the signal. The most common and effective form of clipping is circular clipping, which preserves the angle of the complex signal while limiting the maximum magnitude. Circular clipping follows the input-output relation,

20

$$I_{out} = \begin{cases} I_{in} & : I_{in}^2 + Q_{in}^2 \leq Pp_{out} \\ I_{in} \cdot \sqrt{Pp_{out} / (I_{in}^2 + Q_{in}^2)} & : I_{in}^2 + Q_{in}^2 > Pp_{out} \end{cases}$$

$$Q_{out} = \begin{cases} Q_{in} & : I_{in}^2 + Q_{in}^2 \leq Pp_{out} \\ Q_{in} \cdot \sqrt{Pp_{out} / (I_{in}^2 + Q_{in}^2)} & : I_{in}^2 + Q_{in}^2 > Pp_{out} \end{cases}$$

In hardware implementations, circular clipping is often implemented using a look-up table (LUT). A LUT implementation avoids the need to compute the constellation magnitude, implement the square root, and division functions as are done in U.S. Patent 6,266,320

to Hedberg et al.; such functions are complex operations for digital hardware. With a LUT-implementation, the LUT holds the output I and Q ( $I_{out}, Q_{out}$ ) values for all possible combinations of input values ( $I_{in}, Q_{in}$ ). When the  
5 number of possible input I and Q values is small, the LUT approach is attractive. However, as the number of possible I and Q input values increases the size of the memory used to store the LUT must grow proportionately.  
10 With 10-bit input I and Q values and 8-bit I and Q output values, the LUT would require a memory of size 2,097,152 bytes. If the I/Q constellation is symmetric, then the table may be reduced by one-fourth to 524,288 bytes, but is still quite large. In many applications a LUT-based circular clipper may be impractical when the number of  
15 possible input I and Q values is large.

Therefore, it is desirable to provide an efficient method and system to decrease a peak-to-average power ratio of a communications signal before the signal is amplified by a  
20 power amplifier.

#### SUMMARY OF THE INVENTION

The foregoing and other problems are overcome, and other advantages are realized, in accordance with the presently preferred embodiments of these teachings.

25 In accordance with one embodiment of the present invention a system for baseband amplitude limiting is provided. The system includes a Coordinate Rotator Digital Computer (CORDIC) operating in vector mode having an angle accumulator in addition to a gain device and  
30 limiter. The system also includes a second CORDIC rotator

operating in rotation mode, and is coupled to the limiter.

In accordance with another embodiment a method for limiting the amplitude of complex code division multiple access (CDMA) signals is provided. The method includes the steps of rotating and limiting a CDMA voltage vector magnitude. The next steps generate a CDMA signal based upon the limited and rotated CDMA voltage vector magnitude. The CDMA signal includes at least one in-phase (I) component and at least one quadrature-phase (Q) component.

The invention is also directed towards a method for limiting the peak-to-average power ratio of a plurality of complex telecommunications signals. The method includes the steps of combining  $I_0...I_n$  and  $Q_0...Q_n$  signals to produce an  $I_{in}$  and  $Q_{in}$  composite signal, respectively, and where n is predetermined, e.g., number of channels. The next steps determine a peak power vector and an average power level. The peak power vector is compared to the average power level and adjusted according to the comparison.

In accordance with another embodiment of the invention a program storage device readable by a machine is provided. The program storage device tangibly embodies a program of instructions executable by the machine to perform method steps for limiting the amplitude of complex code division multiple access (CDMA) signals. The method includes the steps of rotating and limiting a CDMA voltage vector magnitude and generating a CDMA signal based upon the limited first CDMA voltage vector magnitude. The CDMA

signal includes at least one in-phase (I) component and at least one quadrature-phase (Q) component.

In accordance with another embodiment the invention is also directed towards a method for efficiently limiting a vector magnitude. The method includes the step of providing a first vector having magnitude and angle. The next step iteratively rotates the vector through diminishing angles to a reference angle such that the vector angle is substantially zero and successively accumulates the angles in an angle accumulator. Once the reference axis is reached the next step limits the vector magnitude to a predetermined magnitude to form a second vector. The last step rotates the second vector through a second angle substantially equal to the resulting angle stored in the accumulator.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the present invention are explained in the following description, taken in connection with the accompanying drawings, wherein:

Figure 1 is a block diagram of a communications system implementing baseband amplitude limiting features of the present invention;

Figure 2 is a block diagram of a preferred embodiment of the baseband amplitude limiting features shown in Figure 1;

Figures 2A-2C are axis diagrams showing phase and magnitude of a vector relative to an average value according to Figure 2; and

Figure 3 is a flow chart of one method for implementing  
5 the baseband limiting features of the present invention  
shown in Figure 2.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, there is shown a pictorial diagram  
10 of a multi-user communications system incorporating  
features of the present invention. Although the present  
invention will be described with reference to the  
embodiment shown in the drawings, it should be understood  
that the present invention could be embodied in many  
15 alternate forms of embodiments.

Still referring to Figure 1 there is shown a Fixed  
Wireless System (FWS) 10 that is suitable for practicing  
this invention. Specifically, the FWS 10 employs direct  
sequence spread spectrum based CDMA techniques over an  
air link to provide local access to subscribers, and  
offers very high quality, highly reliable service. The  
FWS 10 is a synchronous CDMA (S-CDMA) communications  
system wherein forward link (FL) transmissions from a  
base station, referred to also as a radio base unit (RBU)  
25 12, for a plurality of transceiver units, referred to  
herein as user or subscriber units (SUs) 14, are symbol  
and chip aligned in time, and wherein the SUs 14 operate  
to receive the FL transmissions and to synchronize to one  
of the transmissions. Each SU 14 also transmits a signal  
20 on a reverse link (RL) to RBU 12 in order to synchronize  
30

the timing of its transmissions to the RBU 12, and to generally perform bi-directional communications. The FWS 10 is suitable for use in implementing a communications system that conveys multirate voice and/or data between  
5 the RBU 12 and the SUs 14.

The RBU 12 includes circuitry for generating a plurality of user signals ( $\text{USER}_1$  to  $\text{USER}_n$ ), which are not shown in FIGURE 1, and a synchronous side channel ( $\text{SIDE}_{\text{chan}}$ ) signal that is continuously transmitted. Each of these signals is assigned a respective PN spreading code and is modulated therewith before being applied to a transmitter 12a having an antenna 12b. When transmitted on the FL the transmissions are modulated in phase quadrature, and the SUs 14 are assumed to include suitable phase demodulators for deriving in-phase (I) and quadrature (Q) components there from. The RBU 12 is capable of transmitting a plurality of frequency channels. By example, each frequency channel includes up to 128 code channels, and  
10 has a center frequency in the range of 2 GHz to 4 GHz.  
15  
20

The RBU 12 also includes a receiver 12c having an output coupled to a side channel receiver 12d. The side channel receiver 12d receives as inputs the spread signal from the receiver 12c, a scale factor signal, and a side channel despread PN code. These latter two signals are sourced from a RBU processor or controller 12e. The scale factor signal can be fixed, or can be made adaptive as a function of the number of SUs 14 that are transmitting on  
25 the reverse channel. The side channel receiver 12d outputs a detect/not detect signal to the RBU controller 12e for indicating a detection of a transmission from one  
30 of the SUs 14, and also outputs a power estimate value. A

read/write memory (MEM) 12f is bi-directionally coupled to the RBU controller 12e for storing system parameters and other information, such as SU timing phase information and power estimate values.

5

A Network Interface Unit (NIU) 13 connects the RBU 12 to the public network, such as the public switched telephone network (PSTN) 13a or the Internet, through analog or digital trunks that are suitable for use with the local 10 public network. The RBU 12 connects to the NIU 13 using E1 trunks and to its master antenna 12b using a coaxial cable. The SU 14 communicates with the RBU 12 via the radio interface, as described above.

In the illustrated embodiment the SU-RBU air link 15 provides a separate 2.72 MHz (3.5 MHz including guard bands) channel in each direction separated by 100 MHz, 119 MHz, or 175 MHz. In alternate embodiments any suitable separation may be employed. The nominal spectrum of operation is 2.1-2.3 GHz or 2.5-2.7 GHz. However, the 20 system is adaptable such that the frequency can be varied as required. In addition, before the I and Q signals are applied to transmitter 12a the peak-to-average power ratio of the signals are clipped to a desirable level by clipper 20 in accordance with the teachings of this 25 invention. In general, circular clipping operates on the input  $I_{in}$  and  $Q_{in}$  values to compute output  $I_{out}$  and  $Q_{out}$  values such that the peak signal magnitude of the output is  $P_{p_{out}} \leq P_{p_{in}}$ . Circular clipping preserves the angle of the input I and Q pair but limits the peak signal 30 magnitude.

Referring to Figure 2 there is shown a block diagram of a preferred embodiment of the present invention. The COordinate Rotation Digital Computer (CORDIC) rotator is known in the art and will not be discussed here other than to note that CORDIC rotators are normally operated in one of two possible modes. The rotation mode rotates the input vector by a specified angle. The other mode is the vectoring mode, which rotates the input vector to an arbitrary axis, nominally the x-axis while recording the angle required to make that rotation. Vectoring mode essentially performs a change of coordinates from Cartesian (e.g. I and Q) to polar (e.g. magnitude and phase).

15 Referring now to Figure 2 there is shown a block diagram of a circuit incorporating features of the present invention. It will be appreciated that in a preferred embodiment at least two CORDIC rotators 21,22 are used. In an alternate embodiment any suitable rotator or 20 CORDIC-like device may be used. Also, in a preferred embodiment CORDIC rotator 21 is operated in vector mode while CODIC rotator 22 is operated in rotation mode.

Referring still to Figure 2, CORDIC 21 operates in a preferred vectoring mode with inputs  $x_0 = I_{in}$ ,  $y_0 = Q_{in}$ , and  $z_0 = 0$ . In a preferred embodiment the  $I_{in}$  and  $Q_{in}$  signals are 8-bits and the  $I_{out}$  and  $Q_{out}$  signals are 10-bits. In alternate embodiments any suitable bit length could be used. The  $x$ ,  $y$ , and  $z$ , values are iteratively 30 updated using the following set of equations,

$$\begin{aligned}x_{i+1} &= x_i - y_i d_i 2^{-i} \\y_{i+1} &= y_i - x_i d_i 2^{-i} \\z_{i+1} &= z_i - d_i \arctan(2^{-i})\end{aligned}$$

where  $i$  is the iteration number and  $d_i = \pm 1$ . The  $d_i$  values are selected based upon the sign of each  $y_i$  with,

$$d_i = \begin{cases} +1 & y_i < 0 \\ -1 & y_i \geq 0 \end{cases}$$

- 5 For implementation,  $x$ ,  $y$  and  $z$  accumulators are required along with a look-up table (LUT) storing the values of  $\arctan(2^{-i})$ . In a preferred embodiment the number of iterations is ten. However, it will be recognized that any number of suitable number of iterations may be used  
10 to achieve the desired accuracy. The number of iterations and the required angle resolution determines the size of the LUT.

- 15 In vectoring mode with  $I$  iterations, the final outputs of CORDIC 21 are

$$\begin{aligned}x_I &= 1.647 \cdot \sqrt{x_0^2 + y_0^2} = A \\y_I &= 0 \\z_I &= \arctan(y_0 / x_0) = \theta\end{aligned}$$

- Here,  $A$  is the magnitude of the complex input signal ( $I_{in}+jQ_{in}$ ) while  $\theta$  is the angle in radians. As can be seen,  
20 CORDIC 21 operating in vectoring mode with  $z_0=0$  converts the input signal from Cartesian to polar coordinates, with a small scaling on the magnitude.

- 25 Referring also to Figure 3, there is shown a method flow chart illustrating the steps of one method for implementing the invention shown in Figure 2. First, a vector quantity is derived from  $I_{in}$  and  $Q_{in}$  signal values,

step 41. In alternate embodiments the  $I_{in}$  and  $Q_{in}$  may be summed composites of multiple  $I_0...I_n$  and  $Q_0...Q_n$  signals, respectively, as shown in Figure 2. Also in alternate embodiments, summers 26,27 may be any suitable device for combining multiple I and Q signals. The vector amplitude A is then scaled, step 46, by scaler G and hard-limited, step 47, to a predetermined maximum 8-bit amplitude by limiter L as shown in Figures 2A-2C. Scaler G allows input signals that do not exceed the rails of the hard-limiter L to be scaled and may be varied as number of users varies to maintain constant average output power. The scaled and clipped signal polar coordinate signal, along with the accumulated angle, is coupled to CORDIC 22. CORDIC 22, operating in rotation mode effectively rotate the clipped vector through the accumulated angle and produces 8-bit  $I_{out}$  and  $Q_{out}$  components. Knowledge of the input peak-to-average power ratio ( $PAR_{in}$ ) and component specifications allows the scaling G and hard-limiter L value to be chosen to such that a desired output peak-to-average power ratio ( $PAR_{out} \leq PAR_{in}$ ) is achieved.

In the clipping circuit 20, CORDIC 22 operates in rotation mode using similar iterative update equations and initialization  $x_0 = A'$ ,  $y_0 = 0$ , and  $z_0 = \theta$ , where  $\theta$  is the accumulated angle derived from CORDIC 21. In rotation mode, the recursion is identical to vectoring mode except in that the  $d_i$  values are determined by the sign of  $z_i$ , rather than  $y_i$  as in vectoring mode with

$$d_i = \begin{cases} +1 & z_i < 0 \\ -1 & z_i \geq 0 \end{cases}$$

It is appreciated therefore that an efficient baseband circular clipping method and system to decrease a peak-to-average power ratio of a communications signal before the signal is amplified by a power amplifier has been provided. Advantageously, the method and system provided avoids the need for large look-up-tables. The method and system advantageously also offers significant reductions in the number of gates needed to implement the circular clipping relative to the LUT approaches of the prior art when the number of possible input combinations is large. The method and system also advantageously provides efficient baseband circular clipping without mathematically intensive square root, and division functions.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances that fall within the scope of the appended claims.